PERU HEALTHY KITCHEN/HEALTHY STOVE PILOT PROJECT

ANNEX IV – Indoor Air Pollution Monitoring Report

ANNEX IV. Indoor Air Pollution Monitoring Report

Reducing Exposure to Indoor Air Pollution through Household Energy and Behavioral Improvements among Families of the High-Andean District of Inkahuasi-Ferrañafe, Peru

June 2007

Submitted by:
Swisscontact

Summary

In the framework of the cooperation agreement between USAID and Winrock International, in April 2005, the "Healthy Kitchen/Healthy Stove" project was launched to reduce indoor air pollution by implementing improved stoves for better household energy use. The project was implemented in the Inkahuasi district, province of Ferreñafe, department of Lambayeque, in Northern Peru's Andean region, at approximately 3,000 meters (9,842 ft.) above mean sea level. The district has a population of 13,316 living in extreme poverty. The project proposes the introduction of improved stoves to develop a needs-based local market, with a goal of 600 households in the district's communities.

Three institutions have come together to work on local activities: Centro ECO, in charge of the logistics, implementation of improved stoves, and identifying the households that will take part in the intervention; Swisscontact, in charge of monitoring indoor air quality and data management; and Dr. Jay C. Smith, M.D., M.P.H, in charge of evaluating health symptoms and breathing tests associated with indoor air pollution.

The project monitoring was divided into two stages:

- Pre-intervention stage (August-September 2005): Centro ECO completed a survey based on the Inkahuasi district about the population's practices and perceptions. Information was collected about the types of kitchens and use of firewood, among other data. Swisscontact sampled indoor air quality inside 48 kitchens to set a pollutant baseline prior to the implementation of improved stoves. Finally, Dr. Jay Smith collected health data from 78 individuals representing 44 households.

- Post-intervention stage (August-September 2006): After installing the improved stoves, indoor air quality was sampled in 44 kitchens with newly installed improved stoves. Along with the sampling, a survey was completed to gather information about the kitchen and food cooking process on monitoring day. Furthermore, Centro ECO completed a survey and fuel use study to determine changes in the behaviors and firewood consumption resulting from the use of the new technology. A year after the stoves were implemented, a second air quality sampling was completed (August 2007). In this last sampling only indoor air quality was measured, and a survey was conducted in 32 of the households included in the intervention. Centro Eco conducted a perception survey about the improved stoves.

This report includes the baseline information obtained prior to the implementation of the improved stoves and the results obtained in terms of air quality after installing the stoves.

I. Component 1: Practices, perceptions and socio-economic impacts
Institution in charge: Centro ECO

During the months of May and June of 2005, a baseline study was conducted on the practices, perceptions and socio-economic context for the Inkahuasi population. Centro ECO completed a survey with 169 households in 23 communities, as shown in Table 1.

Table 1. Survey intervention

Group	Community	Number of households per group	Sample size
I	Canchachala	52	5
	Amusuy	44	10
	Uyshahuasi	53	5
	Atuncerca	25	2
II	Uyurpampa	171	29
	Chumbeara	40	3
	Romero	41	3
	Piedra Colorada	33	2
III	Marayhuaca	100	9
	Piedra Parada	100	9
	La Tranca	40	3
	Tasajera	63	6
IV	Totora	60	5
	Tungula	60	13
	La Playa	58	5
	Huarhuar	60	5
V	Sinchihual	90	8
	Huasicaj	134	19
	Machaycaj	48	4
VI	Inkahuasi	78	6
	Atumpampa	95	8
	Callita	56	5
	Cochapampa	60	5
Total		**1,561**	**169**

Source: Centro ECO

According to this baseline survey, only 24% of the population in this district has at least some elementary school education. About 90% of the families are farmers, while 3% produce textile crafts or have small businesses.

In over 90% of the households, it is the women who cook; girls 10 and older oftentimes help or even take over their mother's cooking duties. Meals are cooked 2 or 3 times per day, for a total average of 4 to 5 hours. During this time, children under 5 keep their mothers company.

In 61% of the households, the kitchen is a separate room within the house, while in 27% of the cases, the kitchen is a separate building. Only in 8% of households do people cook in the same room used also as a living or sleeping area, and in 4% people cook outdoors.

As for the cooking technology used, 66% of the surveyed households use three-stone open fires, due to low costs and because the fires are also used to heat the room. However, close to 80% of those surveyed said they didn't like cooking on three-stone fires, particularly because of the smoke that builds up in the room. The 23% of the households using three-stone open fires also have some other type of stove, most frequently a semi-closed wood stove without a chimney. Households not using a three-stone stove use semi-closed stoves without a chimney (38%), improved stoves with a chimney (33%), and improved stoves without a chimney (29%).

The most commonly used fuel is firewood, identified as the main fuel in 100% of the households. Over 90% of those surveyed identified dry leaves as the second most common fuel. Firewood is mostly collected by women, with the help of their children and husbands. This activity is carried out twice per week (in 50% of the households surveyed), every other day (21%), every day (20%), or less frequently (9%). The firewood used is generally dry, to prevent smoke generation. Other fuels used on a smaller scale are charcoal and kerosene.

II. Component 2: Indoor air quality
Institution in charge: Swisscontact

During the month of August 2005, respirable particulate matter (PM_4) and carbon monoxide (CO) concentration levels within the cooking environment was monitored in 48 households in 4 communities of the Inkahuasi district, representing over 5% of the 600 households targeted in the intervention. After installing improved stoves, indoor air quality was sampled twice in the households targeted in the intervention: The first sampling was conducted in October 2006, a few weeks after the stoves were implemented, with pollutant concentrations being measured in 44 homes (of the initial 48). The second sampling took place in August 2007, as a follow-up on how the users were operating the stoves, and the efficiency and strength of the stoves over time. During this sampling, PM_4 and CO from 3 models of improved stoves and a three-stone stove installed in the same room and operated on different days were measured in 32 of the homes in the original intervention.

2.1 Methodology

Winrock provided Swisscontact with a protocol for IAP monitoring based on the method used by Intermediate Technology Development Group (ITDG, now Practical Action) in monitoring interventions in Kenya, Sudan, and Nepal. In early 2005, this method was the most accepted and accessible method for use by an implementing NGO. This protocol uses the "gold standard" pump-and-filter method for measuring respirable particulates, and real-time datalogging CO monitors, mounted together at a standard distance from the fire. This approach assumes that PM_4 measurements represent the levels of breathable particles and are a good indicator of the levels of $PM_{2.5}$ and smaller particles, which dominate biomass gas combustion distribution curves.

Measurements were made for 24 hours to determine the PM_4 concentrations, divided in two back-to-back sampling sessions: a 16-hour period during which meals were cooked, and an

8-hour period at night during which no cooking took place.[1] Carbon monoxide was measured on an ongoing basis (recording every minute[2]) for a 24-hour period and kitchen environment temperature was measured while monitoring indoor air quality. The IAP monitoring equipment was provided by Winrock International, while Swisscontact provided devices for temperature measurement.

For reference purposes, this analysis uses the values established as Peru's National Environmental Air Quality (EAQ) Standards. While not established as occupational health or indoor air quality standards, Peru's EAQ standards serve as a framework to evaluate pollution levels in the sampled kitchens. For particulates, as shown in Table 2, the EAQ reference value for particulate matter $PM_{2.5}$ is used as reference to analyze the PM_4 values quantified in this study.

Table 2. Particulate matter (PM) and carbon monoxide (CO) Environmental Air Quality (EAQ) Standards for Peru (according to Supreme Decree 074-2001-PCM)

Pollutant	Period	EAQ
PM_{10}	24 hours	150 µg/m^3
$PM_{2,5}$ (reference)	24 hours	65 µg/m^3
CO	1 hour	30,000 µg/m^3 (26.2 ppm)
	8 hours	10,000 µg/m^3 (8.7 ppm)

In 2005, the World Health Organization published a worldwide update to air quality guidelines. For particulate matter, the new guidelines confirm the fact that a low threshold cannot be set for this pollutant at which there would be no health effects from exposure, and that said effects happen both in short-term exposures (24 hours) and long-term exposures (one year). Even though a value cannot be set to offer complete protection against particulate-related health effects, the WHO set new guideline values in 2006, as shown in Table 3.

Table 3. WHO guidelines for particulate matter (2006)

Pollutant	Period	WHO Guideline
PM_{10}	24 hours	50 µg/m^3
$PM_{2.5}$	24 hours	25 µg/m^3

The new guideline for 24-hour average concentrations of PM2.5 (25 µg/m^3) is thus now significantly lower than Peru's current standards (65 µg/m^3), reflecting a recognition of the seriousness of the health impacts of smoke exposure even at low levels, and creating a more challenging target to meet in typical developing country kitchens, given extreme baseline conditions.

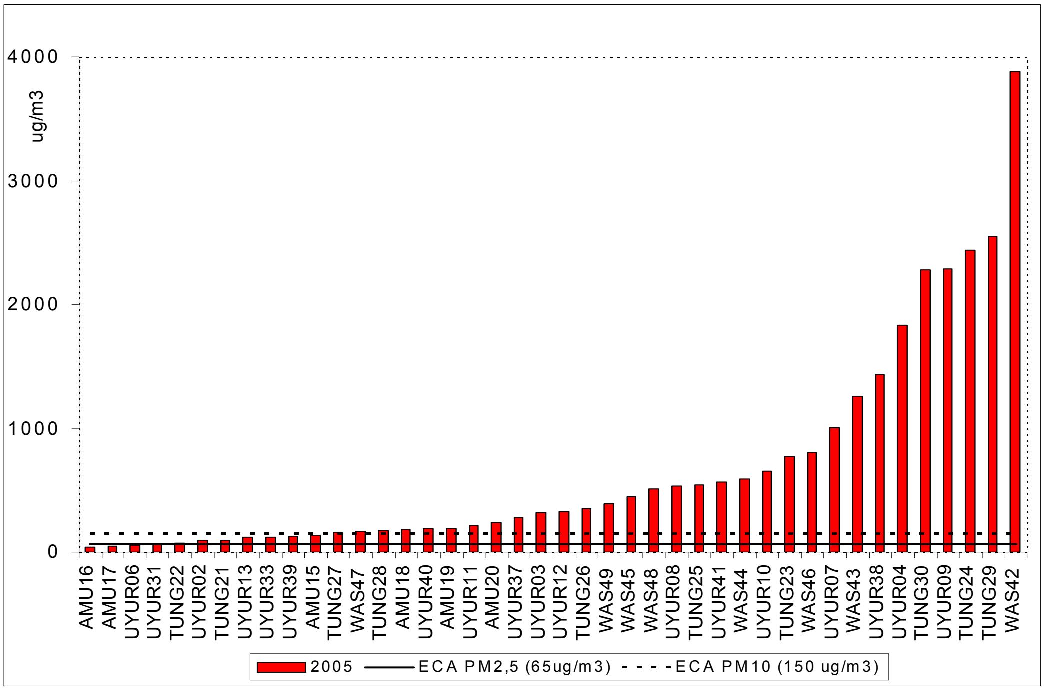
[1] To measure PM_4, a gravimetric method in which air is filtered using a pump and filter (A.P. Buck) for 24 hours was used. In this case, measurements were taken for two consecutive periods of 16 and 8 hours. Particles were captured in special filters that were weighed before and after exposure to determine pollutant mass. The result is the average PM_4 concentration for a 24-hour period.

[2] CO measurements were taken with a real-time device (Industrial Scientific Corporation) that recorded the concentration every minute for a 24-hour period. The hour values are estimated by averaging all the minute values in one hour and the eight-hour values are estimated by averaging the hour values. To consider the valid value, at least 75% of the data required to estimate the average should be available.

2.2 Results: Baseline

In general, the PM_4 and CO concentration levels found in the environments used for cooking were high. The overall PM_4 average reached 680 µg/m^3, more than **ten times** the EAQ reference value for $PM_{2.5}$. 93% of the kitchens had particulate concentrations exceeding this reference value (**see Figure 1.** (n=42)
). The maximum recorded concentration, in a kitchen of the village of Wasicaq, was 3,880 µg/m^3.

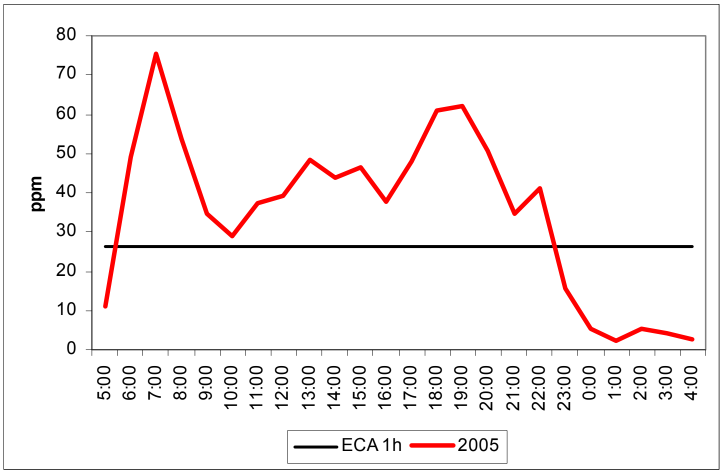
Figure 1. PM_4 concentration (in µg/m^3) in the kitchens sampled prior to installing the improved stoves (n=42)



Note: "ECA" in these figures refers to the Spanish acronym for Environmental Air Quality (EAQ) standards.

For carbon monoxide, average hourly concentrations from 06:00 to 22:00 hours continuously exceed the 1-hour CO EAQ (**see Figure 2**). The mean maximum value recorded in one hour was 176 ppm, over **6 times** the carbon monoxide EAQ for 1 hour. Likewise, the mean maximum 8-hour recorded value is 74 ppm, more than 8 times the corresponding EAQ value.

Figure 2. Average hourly concentration prior to installing the improved stoves (n=42)



Influence of number of meals cooked

Since the sampling coincided with crop harvest days, in 12 of the 48 households sampled only 2 meals were cooked per day: breakfast and supper. During the day, household members were out working on their land. This made it possible to analyze PM_4 and CO concentrations under harvest-time conditions. Results show that the hourly CO concentrations have peaks that coincide with the hours when the kitchen was used for food preparation (**see Figure 3 and Figure 4**). In households where 2 meals were cooked, the average CO concentration between meals (represented by the blue line) fell below the hourly guideline value of 26 ppm, while in households where 3 meals were cooked, the hourly guideline value is exceeded all day long, and it only goes down at night. Though no data are available as concrete evidence, it can be assumed that in kitchens where lunch is cooked, the fire is not completely extinguished, and remnants of the fuel continue to burn or smolder between meals, which accounts for the elevated CO levels. On the other hand, in kitchens where lunch isn't being cooked, the fire is extinguished completely until it is time to cook supper, which brings CO values below the standard during that period of time. In Figure 4, the dashed line represents two-meal averages, including homes where the fire is stoked after dinner.

Figure 3. Average hourly CO concentration in kitchens where three meals were cooked

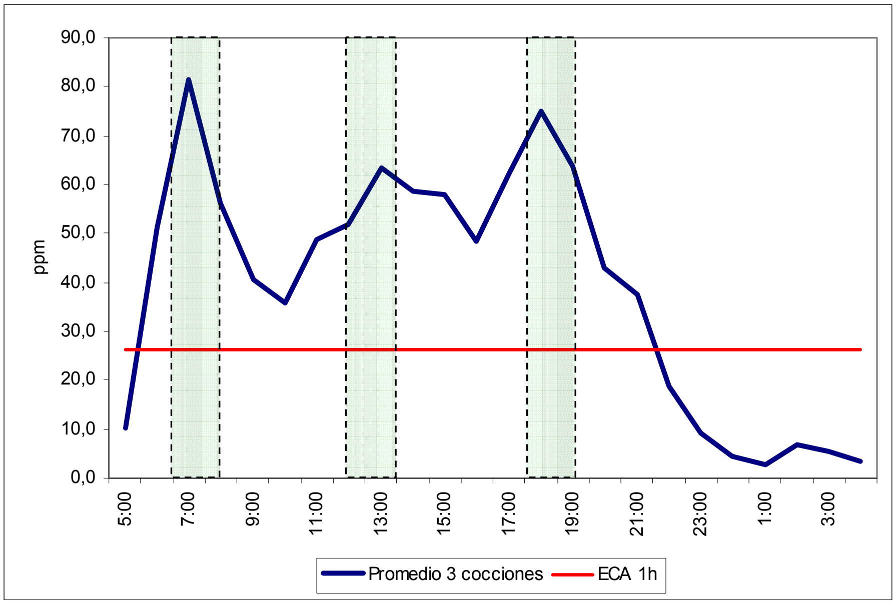
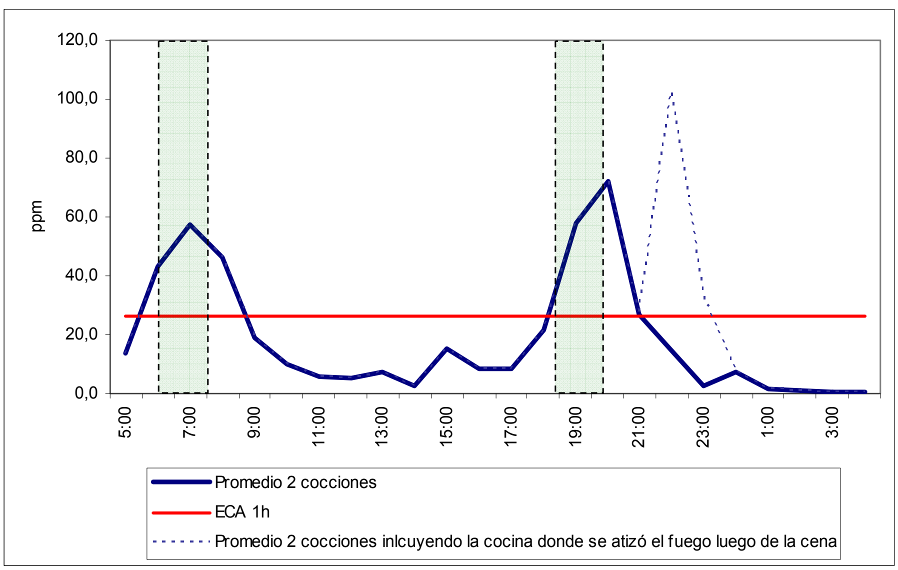
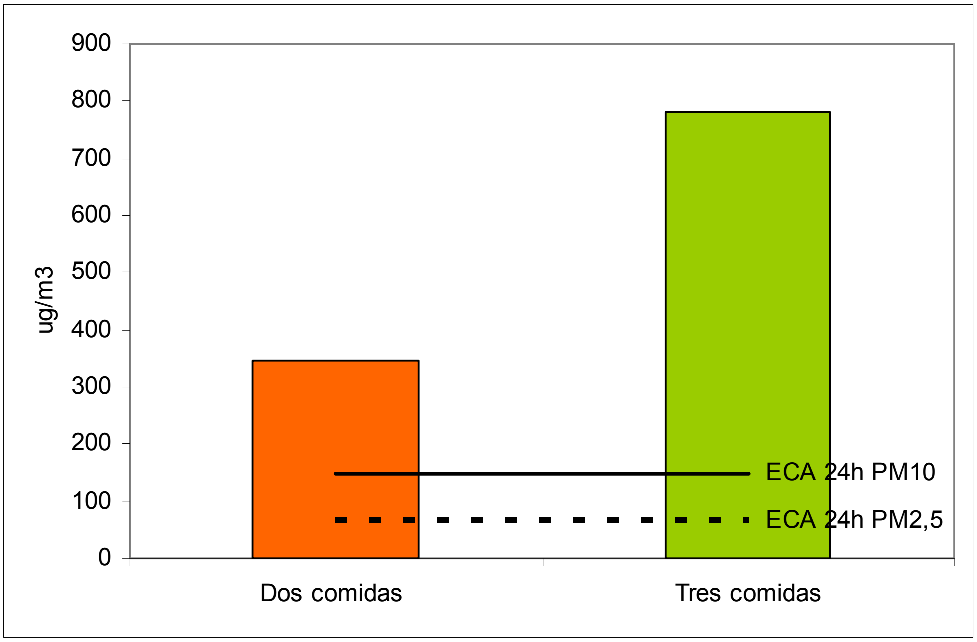


Figure 4. Average hourly CO concentration in kitchens where two meals were cooked



Similarly, as shown in **Figure 5**, the average 24-hour PM_4 concentration in the houses where 3 meals were cooked is substantially higher than in kitchens where only 2 meals were cooked. In both cases, the particulate values recorded far exceed the reference EAQ value for $PM_{2.5}$, reaching on average more than 4 times the standard in the 2-meal kitchens, and about 12 times the standard for the 3-meal kitchens.

Figure 5. Average 24-hour PM_4 concentration in kitchens where two and three meals were cooked per day



Influence of ventilation

At the time the IAP monitoring was being planned, significant differences in roof ventilation were not anticipated. However, a pre-monitoring visit by Winrock and Centro ECO revealed that a number of households had either a rudimentary hole cut-out located in the roof directly over the floor-level open fire, or a carefully constructed hood combined with an elevated cooking platform. The latter finding surprised even the local engineer from Centro ECO who was not familiar with these hoods. Several of these stove hoods were observed, and they were skillfully constructed using the same design, with the material appearing to be a combination of mud and a local fibrous material. The platform consisted of a stack of adobe bricks, enabling the cook to stand while cooking, while the smoke exited easily through the vent.

The monitoring sample was thus adjusted to include a subset of households with hoods/"exhausts." Results showed that the monitored houses that use kitchens with exhausts had the lowest baseline PM_4 concentrations, while the kitchens with no roof opening had the highest concentrations (**see Figure 6**), roughly 3 times that of the kitchens with hoods. The blue bar refers to kitchens without exhausts but with roof openings. Nevertheless, even with hoods, the average indoor concentrations exceed guideline values. The average CO concentration also shows differences. In kitchens with no roof venting, the average hourly CO concentration during the day remained above the appropriate EAQ, except at dawn. On the other hand, kitchens with exhausts exceeded the EAQ in the early morning hours (coinciding with breakfast) after which concentrations dropped significantly, remaining below the EAQ for the rest of the day (**see Figure 7**).

Figure 6. Average 24-hour PM_4 concentration by type of venting on kitchen roofs

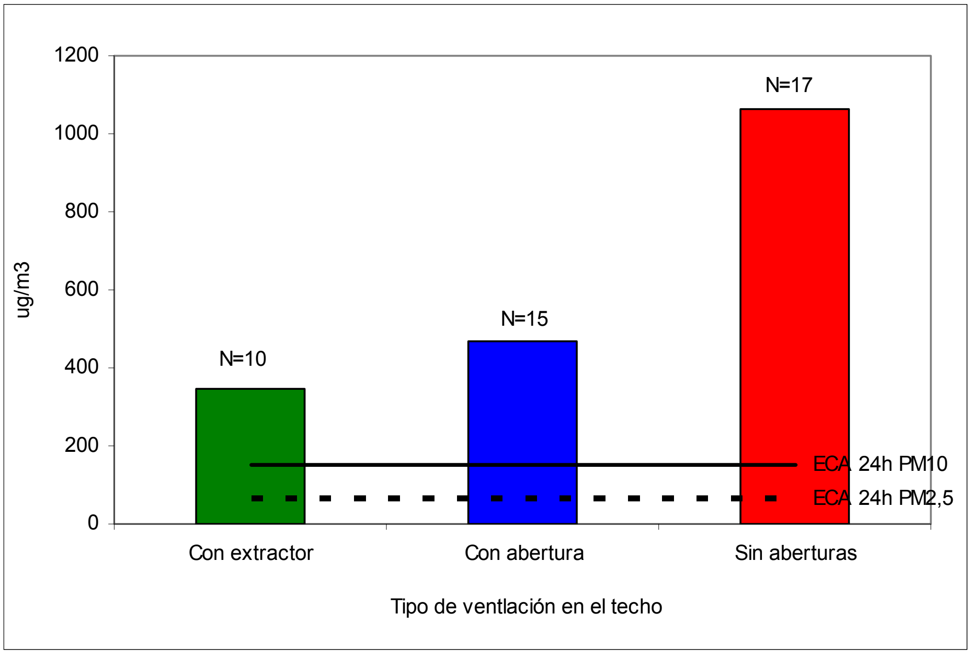
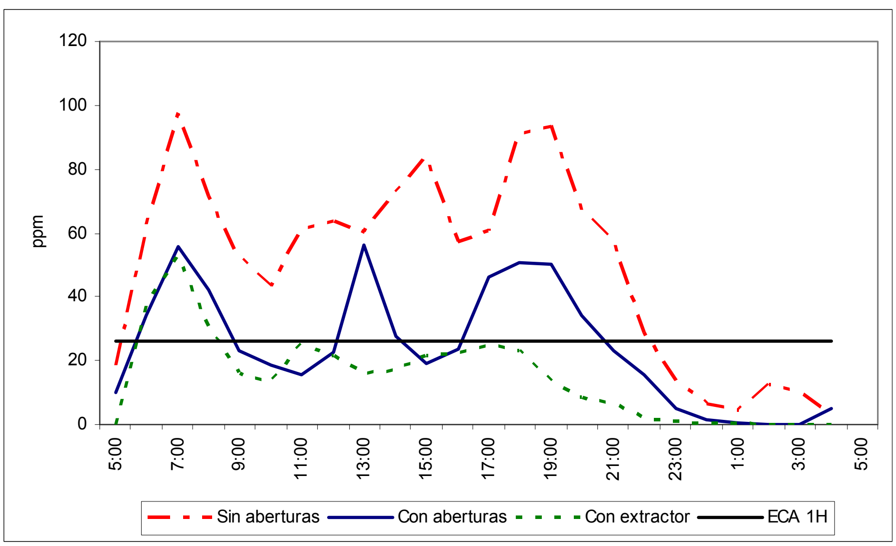


Figure 7. Average CO hourly concentration by type of venting on kitchen roofs



2.3 Results: Post-Intervention

Post-intervention monitoring took place in 44 households (of the original 48 monitored). Further, the baseline PM_4 data for 2 of the households were discarded from the analysis due to sampling issues. Thus, the PM_4 database with complete same-kitchen pre- and post-intervention information includes 42 households (**see Table 4**).

Analysis of the changes in indoor pollutant concentrations reveals a significant reduction in PM_4 and CO levels following the installation of the Inkawasina stoves (and the associated awareness raising and training of promoters and cooks), coming close to the project goal of 80% reduction on average.

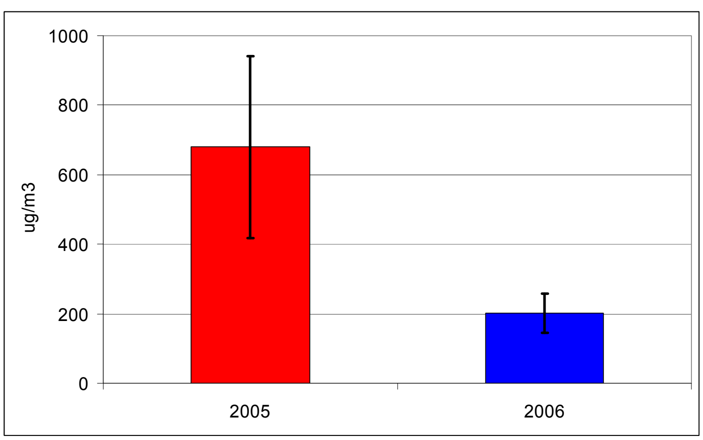
In 71% of the monitored households (30 kitchens), a reduction in PM_4 concentration was recorded. Curiously, no change or a slight increase in particulates was detected in 12 households. For all 42 kitchens, the average PM_4 concentration fell by 70% (**see Figure 8)**, while an analysis of just the 30 houses with reduced PM_4 levels showed a much greater average reduction of 84%, indicating the potential for the intervention to surpass the project goals.

Table 4. PM_4 monitoring results

Community	# of homes sampled*		Average 24h ± SD[3] (μg/m³)		% kitchens above 65 μg/m³	
Monitoring	***2005***	***2006***	***2005***	***2006***	***2005***	***2006***
Uyurpampa	18	18	568 ± 656	219 ± 231	94%	56%
Amusuy[4]	6	6	139 ± 83	313 ± 177	67%	83%
Tungula	10	10	944 ± 989	119 ± 129	100%	60%
Wasicaq	8	8	1006 ± 1206	180 ± 123	100%	88%
Total	**42**	**42**	**680± 868**	**201± 189**	**93%**	**69%**

* The number of homes considered for analysis represents those for which there was complete information for the two samplings (2005 and 2006).

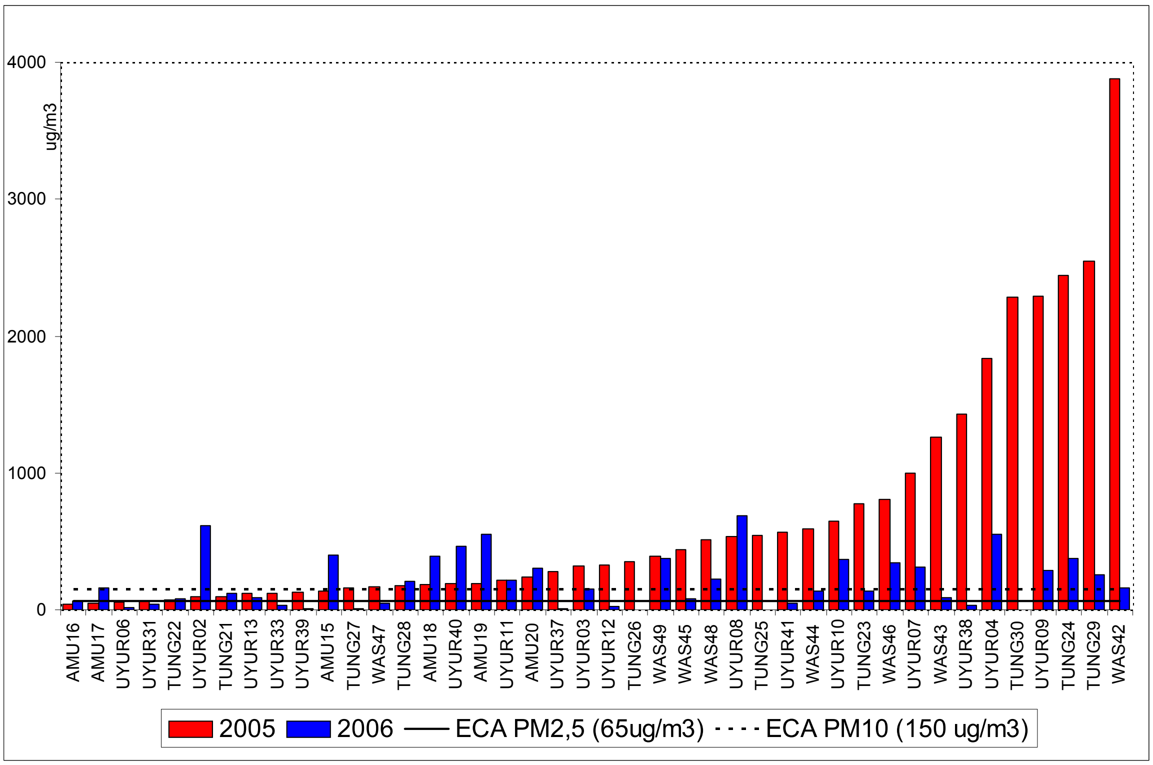
Figure 8. Average 24-hour PM_4 concentration and confidence intervals before (2005) and after (2006) installing improved stoves (n=42)



[3] SD = Standard deviation
[4] All values reported at Amusuy during post-intervention are greater than pre-intervention values. The reason is still unexplained.

The difference between the maximum PM_4 concentrations recorded before and after the intervention is significant. While the maximum recorded value in the baseline sampling was 3,880 μg/m^3, the maximum recorded value post-intervention was 688 μg/m^3 (**see Figure 9)**. This last value was for a stove (in UYUR02) where the pot is smaller than the stove's hole, leaving some room for smoke to escape into the kitchen. Even so, the maximum post-intervention value is up to five times lower than that recorded in the baseline.

Figure 9. 24h PM_4 concentration at μg/m^3 before (2005) and after (2006) installing improved stoves

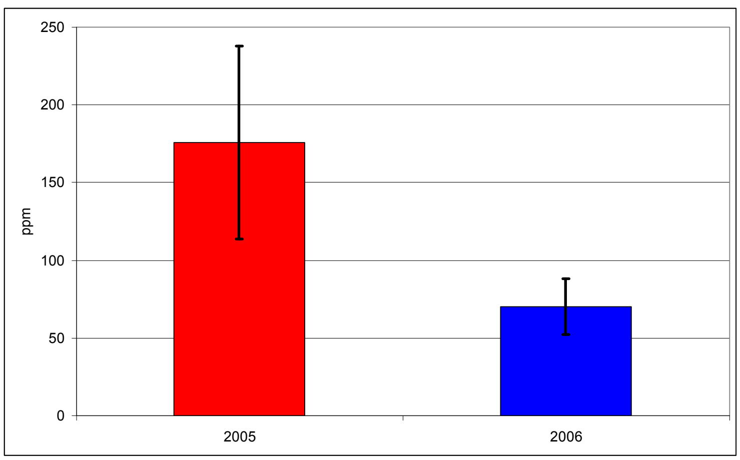


Reductions achieved in the carbon monoxide monitoring tests were similar to PM_4, with CO levels dropping by 71% on average. Including all 42 houses, the average maximum 1-hour value was reduced by 60% after installing the improved stoves (**see Figure 10**). Including only those homes where the CO concentration is reduced (n=30), the reduction was 76%. CO monitoring results are further detailed in **Table 5**.

Table 5. CO monitoring results (average of maximum hourly values)

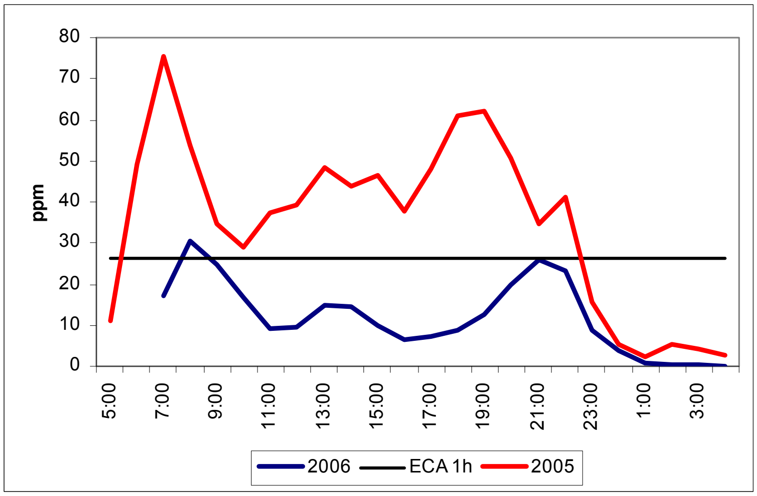
Community	# of homes sampled		Maximum 1h average (ppm)		Maximum 8h average (ppm)		Kitchens above 1h EAQ (26.2 ppm)		Kitchens above 8h EAQ (8.7 ppm)	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Uyurpampa	18	18	195 ± 260	80 ± 73	72 ± 88	25 ± 16	16	16	17	16
Amusuy	6	6	67 ± 41	82 ± 63	28 ± 16	30 ± 25	5	4	5	5
Tungula	10	10	203 ± 200	55 ± 51	96 ± 117	17 ± 12	10	7	10	7
Wasicaq	8	8	179 ± 135	58 ± 32	86 ± 65	22 ± 12	8	7	8	7
Total	**42**	**42**	**176 ± 70**	**70 ± 60**	**74 ± 86**	**23 ± 16**	**39 (93%)**	**34 (80%)**	**40 (95%)**	**35 (83%)**

Figure 10. Average one-hour CO values and confidence intervals before (2005) and after (2006) installing improved stoves (n=42)



By averaging the hourly results of all the kitchens, it can be seen that the CO concentration shows a pattern that can be associated to the meal cooking practices, and the highest peak of the day corresponds to the cooking time of the first meal of the day. Before implementing improved stoves, during the daytime (from 6:00 until 22:00 hours), the hourly CO concentration was found to be over the 1-hour EAQ value of 26.2 ppm (**see Figure 11**). Stove implementation made it possible to lower the day-long hourly averages below the EAQ standard, except for the morning peak.

Figure 11. Average hourly CO concentration in sampled kitchens



August 2007 sampling

The August 2007 follow-up sampling was conducted in 32 homes where the improved stove implemented in the project is still being used. In the 10 homes where it was reported that the stove installed in 2006 was no longer being used, no sampling was performed (**see Table 6**). With the exception of two homes, the rooms in which the stoves were installed and that were sampled in the last campaign are the same rooms sampled in 2006.

Table 6. Homes excluded from the 2007 sampling and reasons reported

Community	Code	Reason
Uyurpampa	UYUR06	The improved stove has been dismantled.
	UYUR09	
	UYUR13	
	UYUR38	The improved stove is in poor condition and the homemaker didn't allow access to the staff to do the sampling.
Amusuy	AMU15	The improved stove has been dismantled.
	AMU16	
	AMU19	
Wasicaq	WAS45	The improved stove is in poor condition and no longer being used.
	WAS46	
	WAS49	The homemaker indicated she is no longer a beneficiary and therefore denied access to the staff to do the sampling.

In general, the results of the 2007 sampling, which took place a year after the improved stove implementation, showed that on average the indoor air pollution in the cooking environments has increased when compared to the 2006 sampling conducted a few weeks after the stoves were installed.

Based on the comments included in the survey by the interviewer, some factors have been identified as possible causes of the increase in tested pollutant concentrations. For instance, it was reported that six stoves had elbows that were in poor condition, in another six stoves the pots used did not fully cover the boilerplates, while in another six homes the users said that the fire burned all day long. In three other homes the users indicated that the stove gave off too much smoke. These factors have been taken into account to conduct the PM_4 and CO analyses (see the ***Analysis*** section).

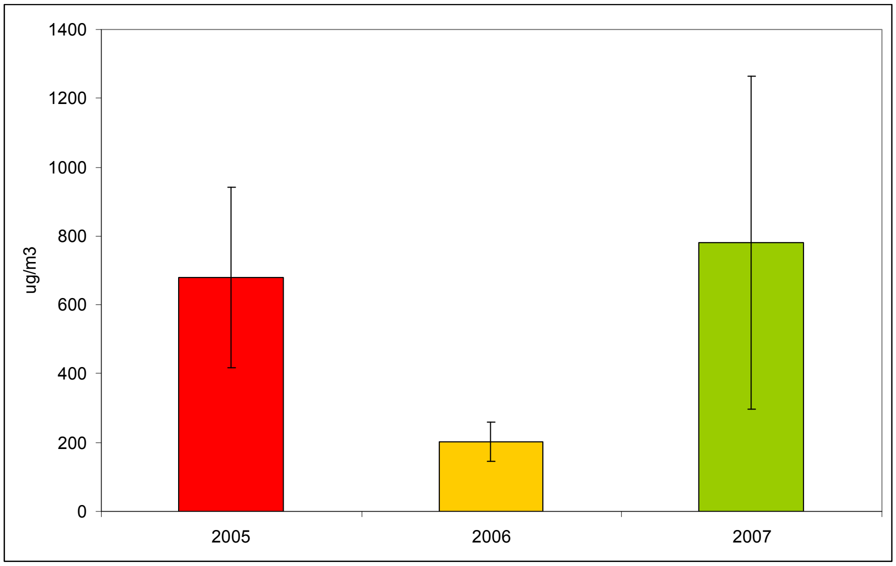
As detailed in **Table 7** below, the overall average PM_4 particulate concentration for the 32 homes is 781 μg/m^3, a value that slightly exceeds the average pre-intervention sampling but doesn't show a significant difference. This value is very similar to the pollution levels measured in the baseline study, since the 2006 measurements, taken a few weeks after implementing the kitchens, were significantly lower. Of 32 homes sampled, six have concentrations higher than 1,000 μg/m^3 and the maximum recorded value is 6,978 μg/m^3 (UYUR08). This was the same home that had the highest PM_4 value in 2006 (688 μg/m^3).

Table 7. PM_4 concentration results summary

Indicators	2005	2006	2007
No. of houses sampled	42	42	32
24h average ± SD	679 ± 868	201 ± 189	781 ± 1.394
Maximum recorded concentration (μg/m^3)	3,880	688	6,978
Minimum recorded concentration (μg/m^3)	44	< 3[5]	11
Kitchens over 65 μg/m^3	39 (93%)	28 (67%)	29 (91%)

[5] < 3 μg/m^3 (reported concentration lower than the method's detection threshold)

Figure 12. Average 24-hour concentrations of PM_4 particulate matter for the 2005 (n=42), 2006 (n=42) and 2007 (n=32) samplings and confidence intervals



Figures 12-14 detail the PM_4 concentrations for the three sampling periods. In **Table 8 below, a** comparative analysis of the three samplings considering the specific changes recorded house by house shows that between 2005 (pre-intervention) and 2006 (post-intervention – first sampling), PM_4 concentrations went down by 81% in the homes targeted in the intervention. In August 2007, a year after installing the stoves (post-intervention – second sampling), the percentage of homes that maintain a reduction compared to the baseline (2005) goes down to 50%. Half of the homes showing reduced PM_4 concentrations had an average reduction of 733 μg/m^3 and the maximum reduction was 2,638 μg/m^3 (**see Figure 15**). Likewise, 50% of the homes showing increased PM_4 concentrations had an average increase of 157 μg/m^3 and the maximum increase was 6,441 μg/m^3.

Table 8. Number of homes showing increased or reduced concentrations of PM_4 particulate matter and average magnitude of change

Period	Parameter	Number of homes	Magnitude in μg/m^3 (difference) Average ± SD
2005-2007	PM_4 concentration reduction	16 (50%)	733 ± 865
	PM_4 concentration increase	16 (50%)	880 ± 1602
2005-2006	PM_4 concentration reduction	23 (72%)	775 ± 953
	PM_4 concentration increase	9 (18%)	157 ± 163
2006-2007	PM_4 concentration reduction	6 (19%)	166 ± 195
	PM_4 concentration increase	26 (81%)	760 ± 1363

Figure 13. 24-hour PM_4 concentration in the 18 homes with reduced concentrations between 2005 and 2007

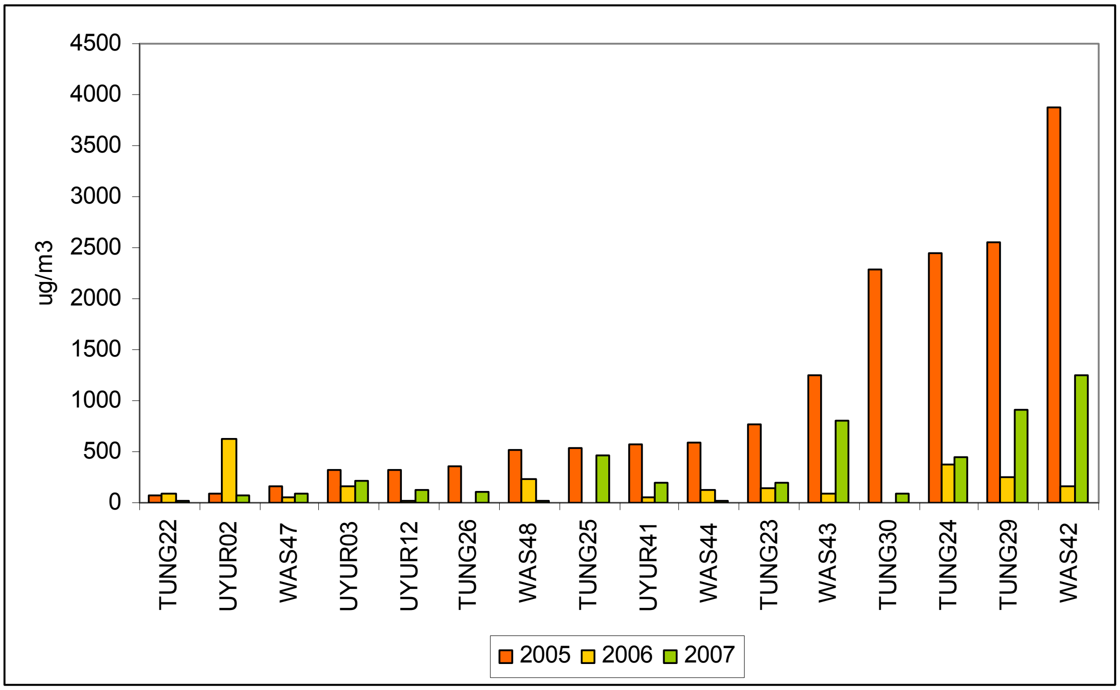


Figure 14. 24-hour PM_4 concentration in the 16 homes with increased concentrations between 2005 and 2007

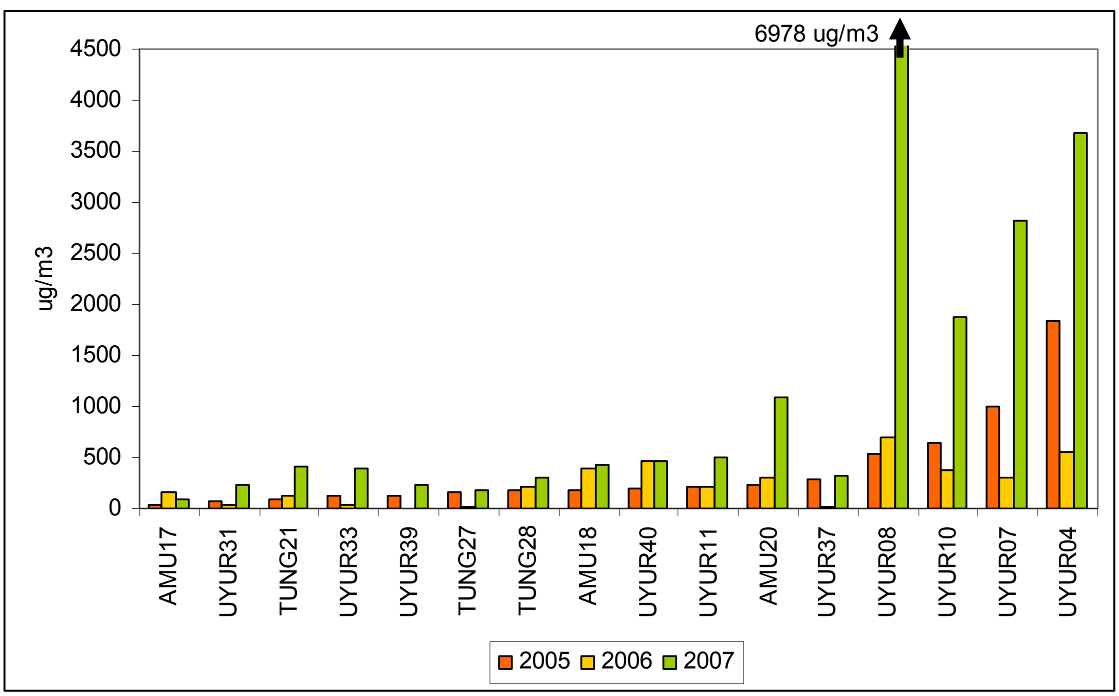
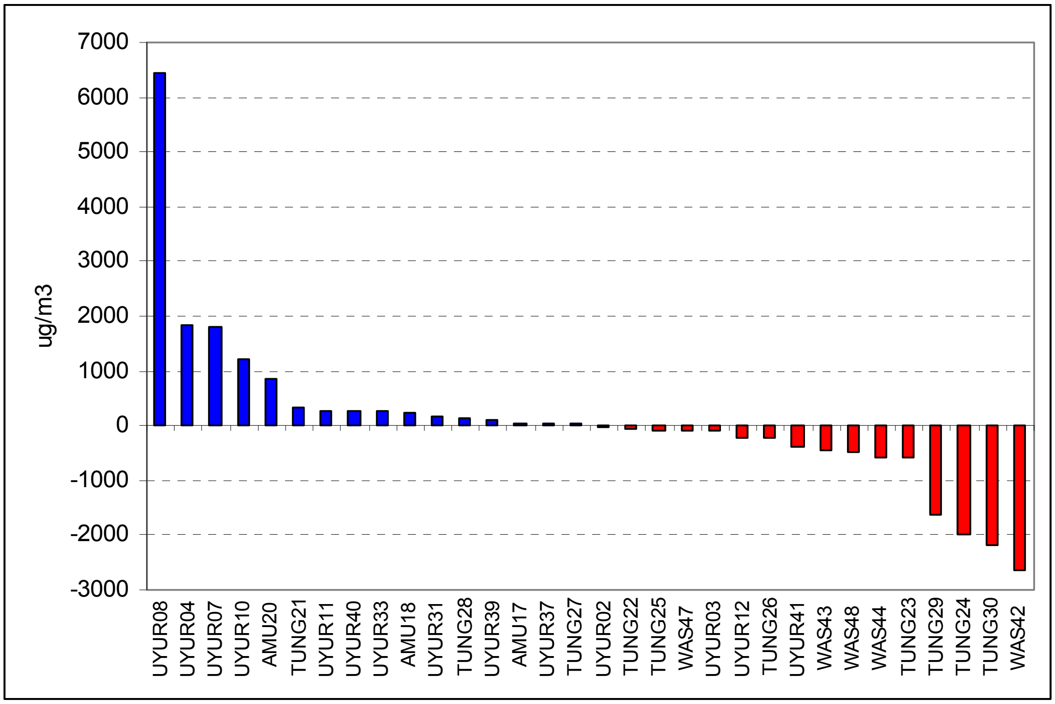


Figure 15. 24-hour PM_4 concentration variation measured in each home between 2005 and 2007 (positive values: increases, negative values: reductions)



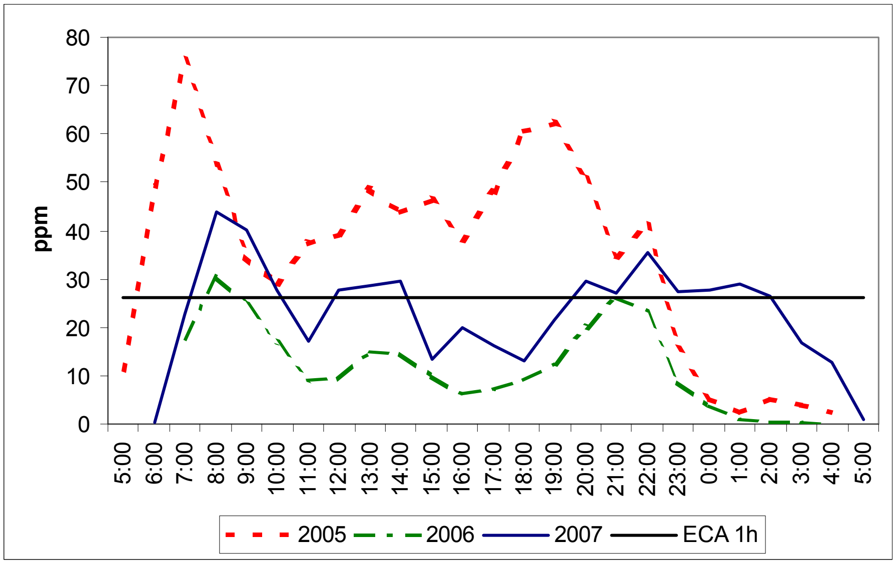
It should be noted that high variability results combined with the fact that the results in each sampled home only reflect the conditions of a day's activity in the kitchen, complicate the interpretation of home-to-home variation comparisons.

Carbon monoxide (CO) results (**see Table 9**) show daily concentrations greater than those recorded in the 2006 sampling, but lower than pre-intervention sampling levels. The three high concentration peaks, which match cooking periods, exceed the 1-hour EAQ limit.

Table 9. CO concentration results summary

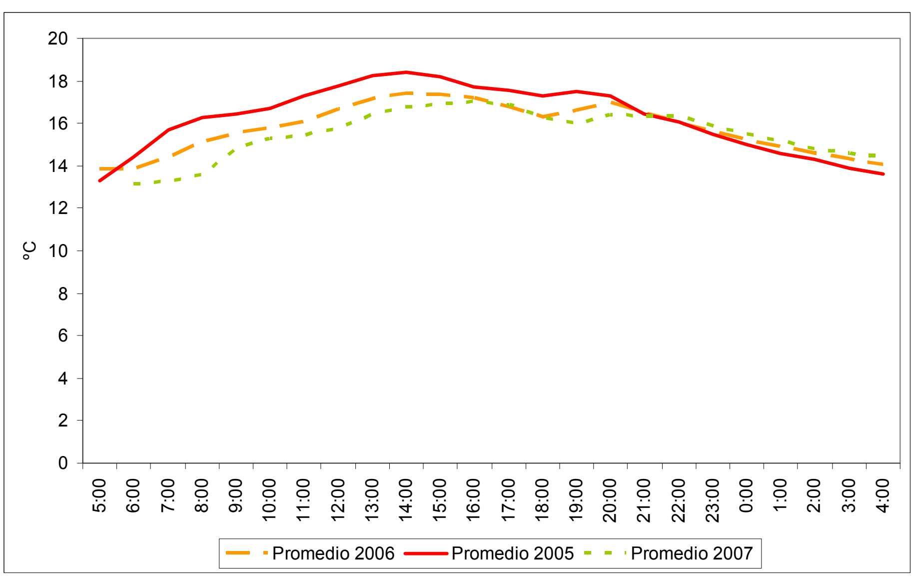
Indicators	2005	2006	2007
# of homes sampled	42	42	32
1-hour maximum average (ppm)	176 ± 70	70 ± 60	147 ± 158
8-hour maximum average (ppm)	74 ± 86	23 ± 16	57 ± 99
Kitchens over 1-hour EAQ	39 (93%)	34 (80%)	28 (88%)
Kitchens over 8-hour EAQ	40 (95%)	35 (83%)	28 (88%)

Figure 16. Daily behavior of hourly CO concentration for 2005 (n=42), 2006 (n=42) and 2007 (n=32) samplings



The results of temperature measurements in the kitchen show that installing improved stoves slightly reduces the average daytime temperature (**see Figure 17**). Between 5:00 A.M. and 8:00 P.M., the temperature in improved stove environments is one to two degrees Celsius lower than in cooking areas with traditional stoves. After 9:00 P.M., temperatures behave similarly. However, it should be noted that house temperatures are also influenced by external factors, such as ambient temperature. Since the samplings took place in different months in the three years, this seasonal change pattern could be causing some of these variations.

Figure 17. Average temperature in the kitchen before (2005 average) and after (2006 average and 2007 average) installing improved stoves ($n_{2005, 2006}$=42; n_{2007}=32)



User satisfaction

The 2007 survey included questions about user satisfaction and their perception of the benefits of using the stoves (see Annex V). In 100% of the monitored homes (N=32) the interviewees said they are happy with the improved stove. All the users have seen a reduction in smoke with the improved stoves when compared to three-stone stoves and are using less firewood (100% said firewood use has gone down by more than 33% with the improved stove and 59% of them said firewood use has gone down by more than 50%).

It should also be noted that in addition to answers in the survey to specific questions about satisfaction with the stove and smoke reduction, the person in charge of monitoring added user comments. In at least three cases (UYUR12, TUNG25, and UYUR40), the women said their stoves gave off smoke.

2.4 Analysis of Results

Air quality monitoring

While it was expected that the results of PM_4 and CO concentrations would be further reduced when compared to the 2006 sampling, under the assumption that a year after the improved stoves were implemented the users would be used to them and would have optimized their use, the 2007 results show that the values have gone up. Even though the data are highly variable and show some significantly high concentrations, low concentrations have also been found. In general, PM_4 levels are similar to those found during the baseline sampling (2005).

While there isn't a single variable that explains these results, the user answers and the interviewer remarks show some indication of the possible reasons behind this finding:

1. Stove elbows are in poor condition: In at least six of the homes surveyed, the users said that the elbow was broken or in poor condition. Since no specific question was included about the elbow, it can't be determined whether the rest of the stove elbows were working properly.

2. The fire burns all day long: In three homes the users stated that the fire is kept burning all day long to prevent the process of firing up the stove every time lunch or dinner needs to be cooked. At night, the environment is closed off and the fire keeps burning until all the remaining firewood is consumed. This is the only indicator that could explain the extremely high values in UYUR08.

3. The pots don't completely cover the burners: In six homes, it is reported that the pots being used fail to completely cover the burner hole.

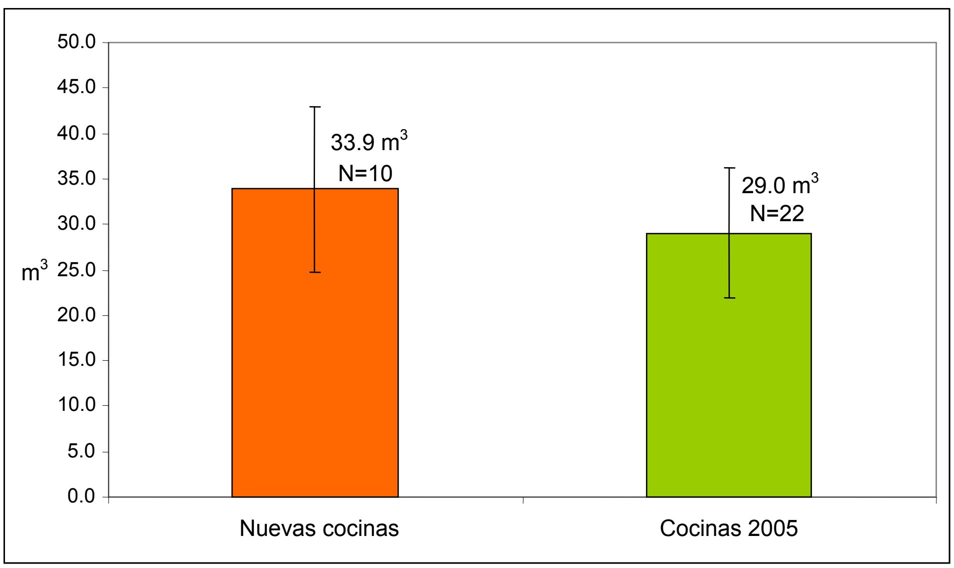
4. Use factors: There could be factors that haven't been included in the survey, such as failure to clean the inside of the stove or the chimney. After a year's use, if stove parts are not maintained, the conditions could be such that the gas exhaust is being blocked off.

It should be noted that the homes where air quality was sampled were the first ones to receive improved stoves. Thus, it's very likely that the elbows weren't in top-notch condition, since they were the first elbows to be fabricated in a place far from the intervention site. Furthermore, apparently promoters who implemented the stoves didn't have all the visuals needed to properly teach users how to use and maintain the stoves when these first stoves were installed.

Other factors that may influence pollutant concentration in homes, such as the size of the room, the number of doors and windows, the time used for cooking food, and the moisture content of the firewood used, have been considered in the survey. The results obtained do not fully explain variations in the measured concentrations. In general, the following parameters were evaluated:

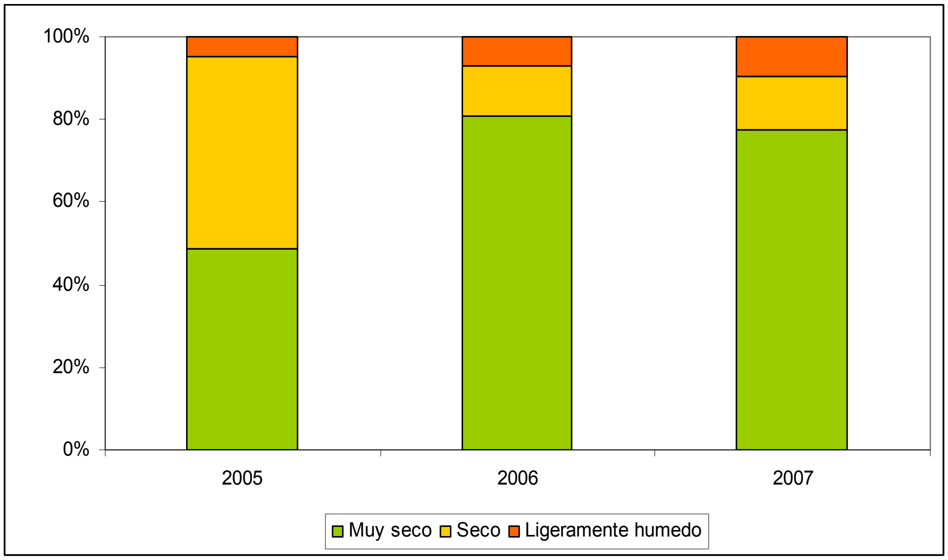
1. Room size: While the 2005 and 2006 measurements weren't accurate enough, in 2007 these measurements were taken carefully, and this gave a more accurate value of each room's size. Since some kitchens were relocated from the sites identified during the 2005 monitoring to build the improved stoves, data were separated into rooms that stayed in the same location as the originally sampled room and rooms that were relocated due to the improved stove. The average in the new rooms is slightly higher than that of the original rooms, even though the differences were not significant (**see Figure 18**). Even so, if this trend is correct, the increased volume in the room should result in a reduction of measured pollutant concentrations.

Figure 18. Size of original kitchens and size of new kitchens used to install the improved stove



Firewood moisture content: In the three years, surveys indicate that in more than 90% of the homes dry or very dry firewood was used for cooking (**see Figure 19**). The use of slightly moist firewood was reported in two homes in 2005 and in three homes in 2006 and 2007.

Figure 19. Moisture content of firewood used for cooking: Percentage of homes using very dry, dry and slightly moist firewood (N_{2005}=42, N_{2006}=42, N_{2007}=32)



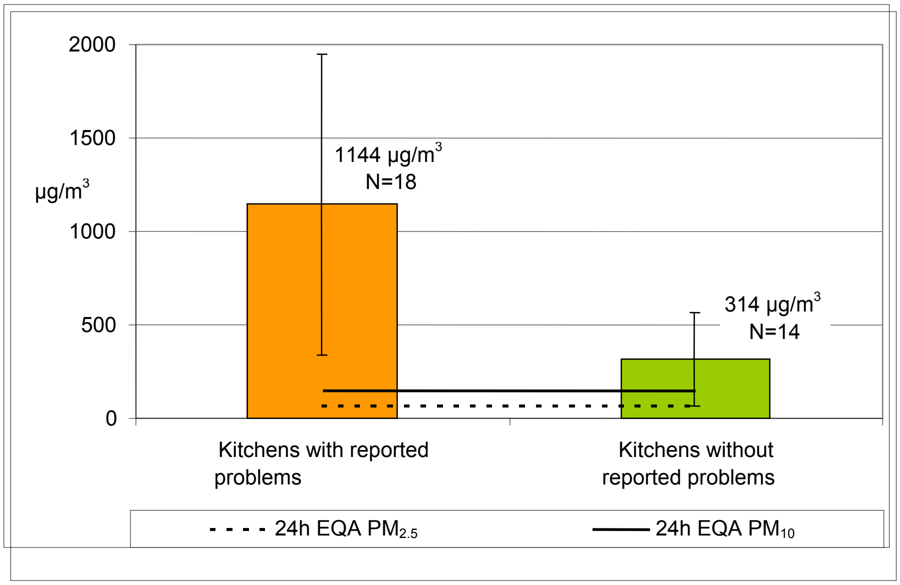
For these reasons, the data from the 2007 sampling were separated into two groups. The homes where one of the above factors had been reported (elbows in poor condition, fire burning between meals, a smoking stove or pots that don't completely cover the burner) were identified. This group was compared to the group of remaining kitchens, where the stoves apparently had not had any problems. In all, 18 homes were identified where one or more of these problems had been reported (**see Table 10**) while the remaining 14 didn't report any issues.

Table 10. Homes reporting a problem with the stove

Problem observed	Number of homes	Codes
Elbows in poor condition or broken	6	UYUR03, AMU17, AMU18, AMU20, UYUR31, WAS47
The fire keeps burning all day long	6	UYUR04, UYUR08, TUNG21, UYUR40, WAS42, WAS43
The users indicate that the stove gives off smoke	3	UYUR12, TUNG25, UYUR40
The pot doesn't completely cover the burner	6	TUNG23, TUNG29, UYUR33, WAS42, WAS43, WAS47

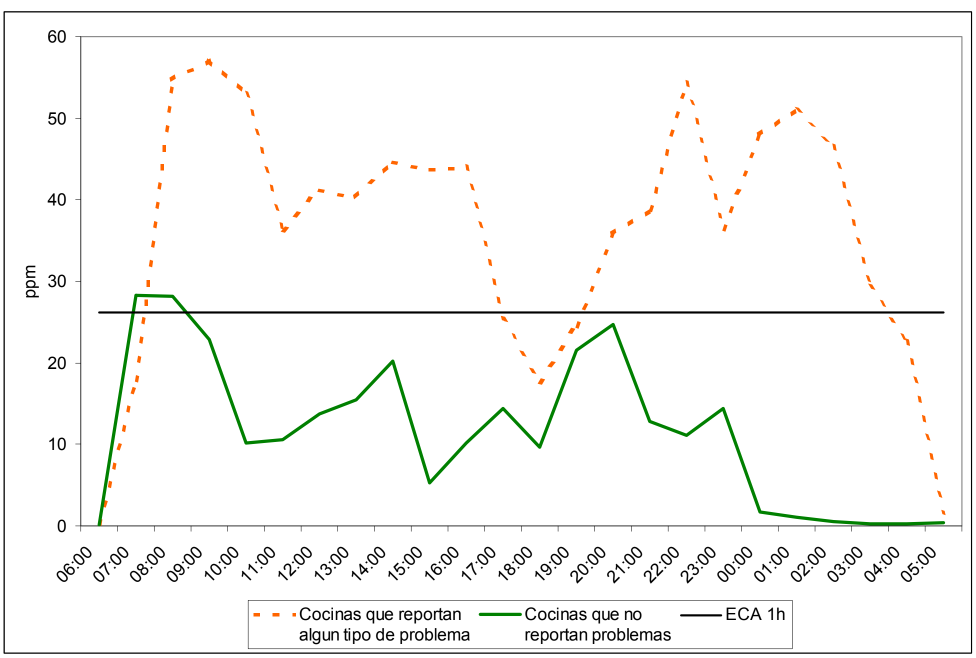
Results show that the average particulate concentration in the group that had some type of problem was more than three times the average in homes without reported problems (**see Figure 20**). Of the 14 homes where no problems were reported with the stove, only three (21%) are below the EAQ $PM_{2.5}$ standard.

Figure 20. Average 24-hour concentration of PM_4 particulate matter in homes where some kind of stove problem was reported vs. those where no problems were reported (2007)



With the same criterion, a comparative analysis was conducted of the CO hourly data, and a difference was found between homes with and without reported issues. In the second case, the average hourly behavior during the day is found to be below the 1-hour EAQ CO level, except for a morning peak, which exceeds it slightly (**see Figure 21**).

Figure 21. Daily behavior of hourly CO concentration in homes where some kind of stove problem was reported vs. those where no problems were reported (2007)

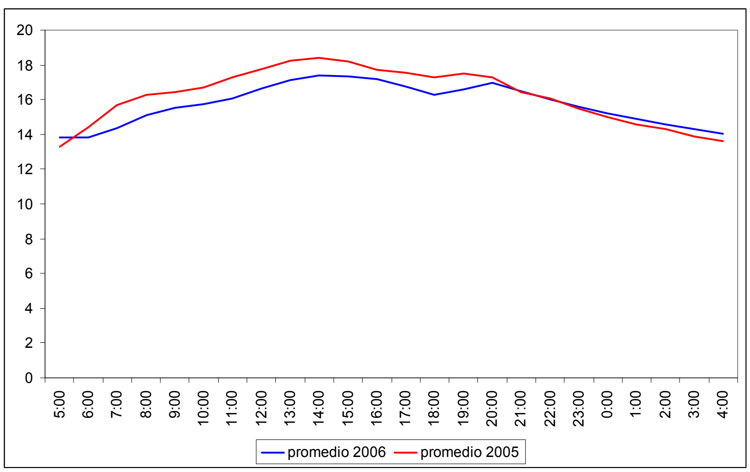


The results of temperature measurements in the kitchen show that while installing improved stoves slightly reduces the average, this reduction is not significant. This is important because of the cold climate; it is important that the stoves continue to generate some heat.

Observations

The Winrock team was quite pleased with the overall reduction in indoor pollutants in the household sample. However, because no change or even an increase in smoke levels was detected in 12 households, Winrock, Centro ECO, and Swisscontact shared field notes and made visits to these households to seek any obvious explanations of this unexpected result. Several observations were made of both structural and behavioral factors that may have contributed to zero smoke reduction or an increase in smoke levels. Structural factors included a chimney that was constructed too short, such that exiting smoke was able to re-enter the kitchen. Behavioral factors included leaving one pot hole open while cooking; using damp leaves as fuel; and cooking over an open fire immediately outside the kitchen door, during a day of celebration. Centro ECO conducted follow-up visits to address both types of factors. Because of these observations and due to the fact that many families had only had their stoves for a matter of weeks, Swisscontact conducted the third round of monitoring in July 2007 to verify pollution changes after a more substantial adjustment period.

Figure 22. Average temperature in the kitchen before (2005) and after (2006) installing improved stoves (n=42)



Exposure patterns

The exposure of women and young children to indoor air pollution was included in the survey through questions about the amount of time they spent in the kitchen while the fire was burning. This section of the survey was repeated in the three years assessed (see Peru IAP Report Annex V, section H15).

The results show that the women stay in the room used as a kitchen while the fire is burning[6] anywhere from 3 hours and 20 minutes to 4 hours on average[7] during the day. The time required to cook each meal (breakfast, lunch and supper) ranges from 1 hour to 1 ½ hours on average. The 2007 results show a slight reduction in women's exposure times, with an average of 2 hours and 51 minutes (**see Table 11**).

It is worth noting that when these results are compared to the answers to the question about cooking times in the monitoring survey (see Peru IAP Report Annex V, Section G), the averages for the three years are very similar. According to these figures, and assuming that the women are in the kitchen the entire time it takes to cook the food, exposure times would be approximately 4 hours.

Table 11. Average exposure time for women and children in kitchens and time it takes to prepare meals (Values represent total time in one day)

Periods evaluated (hours and minutes)	**2005**	**2006**	**2007**
Exposure of woman to fire burning	3:18	3:23	2:51
Exposure of child to fire burning	2:11	1:58	1:48
Total food preparation time	4:00	3:38	3:49

In the case of young children, in 2005 the average time spent in the kitchen while the fire was burning was 2 hours and 11 minutes; the shortest time recorded was 15 minutes and the longest time was 6 ½ hours. This value was slightly reduced in the next two samplings, after the installation of improved stoves.

Figures 23-28 on the next page show exposure patterns during the day both for women and children.

[6] The survey only assesses the number of hours spent by women or young children in the kitchen while the fire was burning. It does not include the number of hours the fire was not burning or the exposure of other people (for example, people eating during meal times).

[7] The survey included a question about exposure and a question about the time it took to cook the meal. Both are taken as exposure indicators. In both cases, actual exposure is not reflected, since no information is included about the additional time women may have spent in the kitchen (eating, cleaning up, etc.).

Figures 23 – 28. Women (left) and children (right) exposure patterns vs. average hourly CO concentration in 2005 (n=42), 2006 (n=42), and 2007 (n=32)

Figure 23 – Women 2005

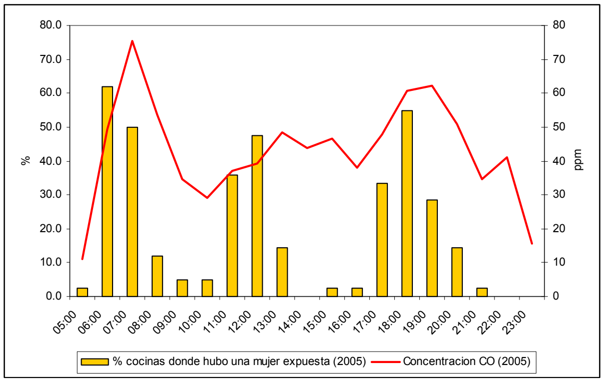


Figure 24 – Children 2005

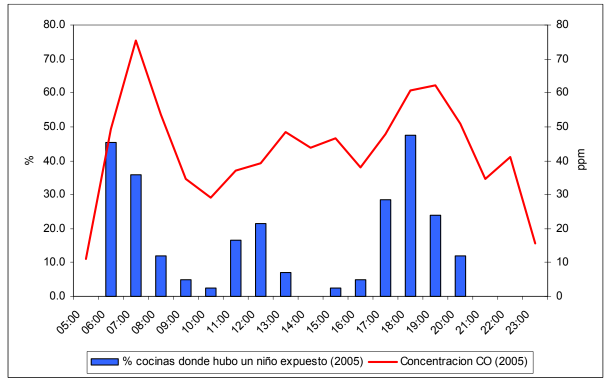


Figure 25 – Women 2006

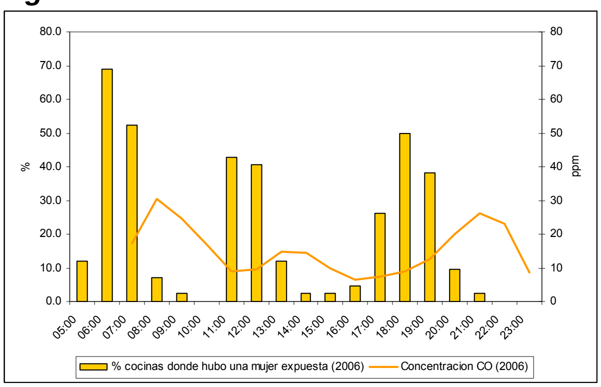


Figure 26 –Children 2006

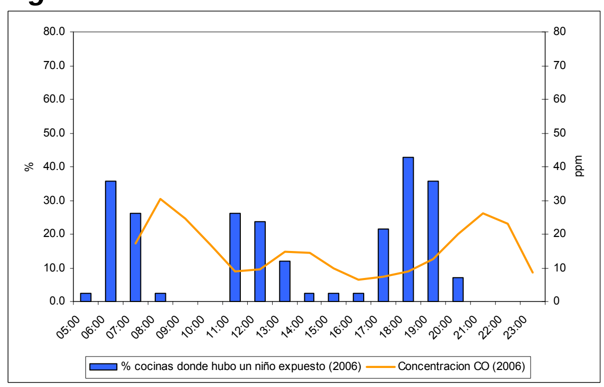


Figure 27 – Women 2007

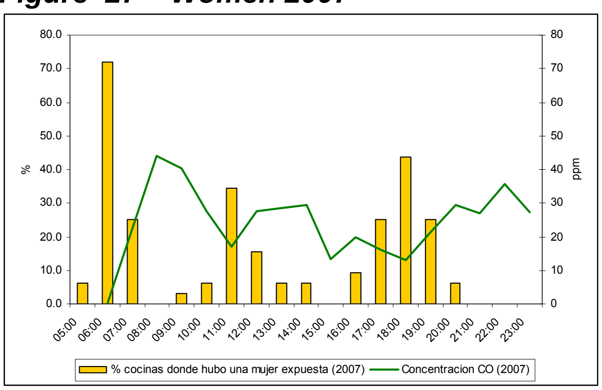
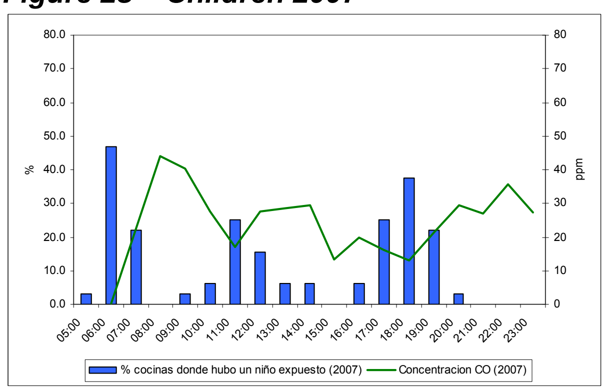


Figure 28 – Children 2007



Interestingly, the installation of the improved stoves appears to not have significantly reduced the time used to cook, or altered exposure patterns. It is important to note, however, that the actual CO concentrations that the women and children are exposed to are significantly lower.

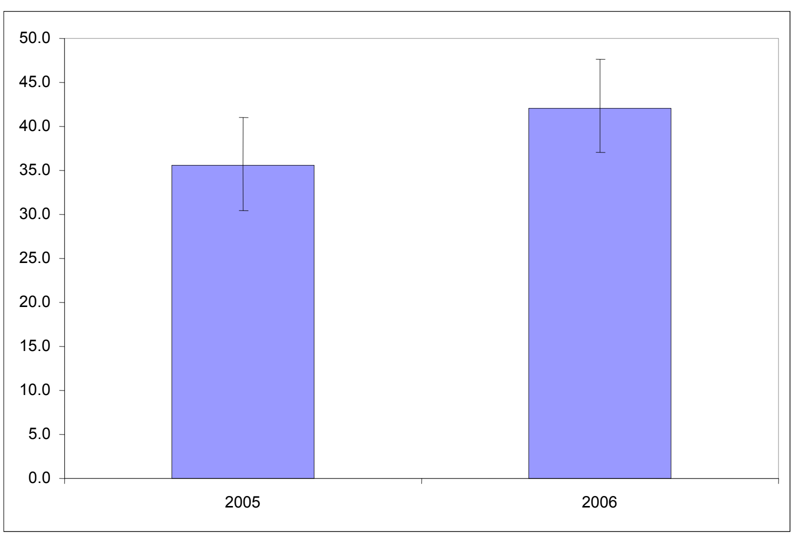
Additional relevant information

To supplement the air quality monitoring, surveys were conducted in the homes monitored, in order to learn about the activities performed by the families while pollutants were being measured in their homes. Information was also collected about the houses' infrastructure.

The average area of the monitored kitchens is 12 m^2 (129 ft^2). The kitchens sampled are mostly adobe constructions (47 of 48), except for one that has wooden stick walls. They have dirt floors and the roofs are a conglomerate of reed, clay, and plastic, as well as steel and wood sheets. The number of members per household ranges from 4 to 8 people, typically consuming coffee and a high-carbohydrate diet (potato soup, thin noodles and stews, roasted corn, parboiled tubercles, and wheat tortillas), which requires a cooking time of 1 to 2 hours.

In 26 of the 42 houses surveyed, the location of the room used as the kitchen was modified to install the improved stove, responding to an interest by the users to change both the stove and the cooking area. In 2005, the average volume of the monitored kitchens was 35.5 m^3 (1,236 ft^3). By 2006, there was a slight increase to 42.1 m^3 (1,486.7 ft^3), as can be seen in **Figure 29**. As shown, this increase is not very quantitatively significant, but the modification included, in some cases, an increase in the number of windows per kitchen and the width of the windows. It is worth noting that this point was not further explored as it wasn't considered a factor to be changed in the intervention population, and therefore the relationship between this parameter and the reduced concentrations of PM_4 and CO has not been looked into.

Figure 29. Average volume variation in monitored houses, in m^3



III. Component 3: Evaluating health symptoms and lung function
Person responsible: Dr. Jay C. Smith, M.D., M.P.H.

In August 2005, data were collected about adult respiratory health in a sample of houses for the project's baseline. With the help of a nurse who translated from Spanish into Quechua, Dr. Smith conducted breathing tests in 78 individuals of 44 separate households in 3 villages and applied questionnaires about lung symptoms and diseases among those who cooked at home (64 people). These tests were carried out in the same homes where indoor air quality was monitored. Spirometric breathing tests were completed in 74 individuals, for interpretation purposes. Findings were anticipated as to the degree of symptoms and breathing obstruction comparable to what would happen if those evaluated had been smoking for years, even though none of the subjects smokes tobacco on a regular basis (none of the 40 women smokes and only a few of the 34 men smoke occasionally). With these data, the goal was to be able to show significant changes after a year of reduced smoke exposure after installing the improved stoves. Results of the health assessments are included in Peru IAP Report Annex VI.

Airway obstruction while breathing out (spirometric evaluation) is the standard measurement of destruction and inflammation caused by smoking. Expiratory capacity during the first second of strong exhalation in young, healthy lungs is typically greater than 85% of the total forced capacity. This number decreases with age and decreases faster in smokers than in non-smokers. Previous research has shown that the decrease is more significant in women exposed only to indoor air pollution as a result of cooking with biomass. However, this research shows that for the first year after quitting smoking, the reduction not only stops, but is slightly reversed. The comparable effects as a cause of obstructive pulmonary disease suggest that this effect must also be seen in a non-smoker population with biomass smoke exposure as a result of cooking.

Spirometric tests found a wide range of results, as is to be expected in a population with varying ages (and a different number of years of exposure to indoor smoke). The youngest person had a FEV1% (forced expiratory volume in 1 second as a % of the total volume exhaled in 1 breath) of 93.5%. Among the other subjects, 8 had an FEV1% lower than 70%. This is part of a clinical definition of a chronic obstructive pulmonary disease (COPD). Another 27 had a lesser degree of obstruction, indicated by a FEV1% greater than 70% but lower than 80%. The average result for half of the elderly people evaluated was less than 75%. If the hypothesis that installing the improved cookstoves can reduce and partially revert COPD is true, then an improvement in the average FEV1% should be observed one year after initial replacement of the open-fire stove. Furthermore, this may correlate to the degree of indoor air quality improvement reached, even if the numbers are too low to reach statistical significance for each subgroup analysis.

The findings in the breathing symptoms and diseases questionnaire could be a little more difficult to interpret with regards to the anticipated improvements. The baseline data don't show a trend of the worst symptoms in those with the worst breathing evaluation results (17 people fit the definition, in the case of chronic bronchitis; and their average FEV1% results were virtually identical to those of the total sample). There are several potential explanations for this, including a conscious or unconscious competition among participants in spirometry testing. In any case, the elevated prevalence of chronic productive cough

(86% of the cooks) was obtained as expected. Improvements in this area can result in a helpful rate of quality of life changes.

IV. Conclusions

Implementing improved stoves in Inkahuasi kitchens significantly reduced indoor air pollution levels both for PM_4 and CO during the first weeks post-intervention (2005 vs. 2006). Pollution levels have been reduced by approximately 70% in sampled kitchens for both pollutants.

The results obtained a year after implementing the stoves don't show the same gains seen in the first weeks. The average PM_4 and CO values increased when compared to the values obtained a few weeks after installing the stoves, reaching levels similar to those recorded prior to installing the improved stoves. Even so, pollution levels were reduced in 50% of the sampled homes.

Factors that could be causing a greater amount of indoor emissions could include damaged stove elbows, pots that don't completely cover the burner hole, and the local custom of letting the fire burn all day long. Other factors, such as poor stove maintenance or upkeep, cannot be ruled out as they could be causing blockages in the chimney. Faulty stove construction could also be a factor. All of these factors, both about the quality of the elbows and the ability of the users to properly maintain the stoves, could be due to the fact that these were the first homes in the intervention, which causes them to show "learning-curve" issues inherent to the beginning of a new project.

The chimney draw in the homes should also be evaluated, considering the elevated concentration values reported in the last sampling. The height of the chimneys needs to be checked, as well as the materials used to build them and the covering around the roof exhaust, so that pollutants are carried outside of the building, rather than the opposite.

The citizens who decided to enter the new stove construction program have not only implemented the improved stoves in their homes, but many have also adapted new areas to install the improved stoves. This behavior could be due to the work of various organizations that have been developing various programs to improve living conditions for the inhabitants in areas such as basic sanitation and healthy housing.

Users have said they are happy with the stoves and have reported less smoke, less time needed to cook food, and significant savings in firewood use. Although slight, indoor air pollution exposure patterns have shown some reduction in the time women spend in the kitchen exposed to pollution.

V. Lessons Learned

While it has been shown that the installation of improved stoves to replace traditional three-stone stoves would significantly reduce air pollution levels in cooking environments, there are factors that, if not controlled, in the long term would cause an increase in pollution. While these factors have not been fully identified, the following can be mentioned: stove elbows that get damaged quickly; or pots that don't completely cover the burner holes. Furthermore, traditional household practices, such as keeping the fire burning all day long, could be contributing additional emissions.

Because of these factors, in order to efficiently reduce indoor air pollution, improved stove programs should pay special attention to technical matters, such as quality control for the elbows produced and supplies used to build longer-lasting stoves; and reinforcing behavioral messages on stove maintenance and upkeep, including chimneys. Thus, the implementation of improved stoves should go hand in hand with a "best practices" program regarding their use, installation, and maintenance that will allow users to feel comfortable with the stoves and use them efficiently.

Support for local coordinators is critical for the project to achieve the desired objectives. Indoor air monitoring is more feasible for technical staff with the support of local promoters, so that the sampling can be completed within the scheduled time.

ACKNOWLEDGMENTS

Our recognition and thanks to:

A. USAID for the initiative to develop and fund the project.

B. Winrock International for trusting Swisscontact to work on the indoor monitoring component for this project.

C. Centro ECO for the coordination activities completed throughout the project and to the promoters for their support and availability for local coordination.

APPENDIX A: PM_4 and CO values per home

House code	24h PM_4 average (µg/m3)		1h maximum CO (ppm)	
	2005	2006	2005	2006
AMU15	136	401	73	130
AMU16	38	64	139	10
AMU17	44	161	25	13
AMU18	183	390	71	58
AMU19	192	554	66	135
AMU20	240	307	28	148
TUNG21	94	122	31	38
TUNG22	70	83	41	26
TUNG23	774	135	153	80
TUNG24	2439	375	625	189
TUNG25	543	n.d.[8]	131	38
TUNG26	351	n.d.	127	7
TUNG27	163	10	118	25
TUNG28	177	211	69	56
TUNG29	2546	256	238	57
TUNG30	2281	n.d.	495	37
UYUR02	94	617	74	138
UYUR03	316	153	111	142
UYUR04	1835	548	1067	46
UYUR06	56	16	31	83
UYUR07	1001	310	266	104
UYUR08	537	688	68	101
UYUR09	2290	288	518	91
UYUR10	650	370	261	325
UYUR11	215	213	119	62
UYUR12	328	22	75	47
UYUR13	116	90	40	94
UYUR31	66	43	13	37
UYUR33	121	30	54	26
UYUR37	280	10	393	45
UYUR38	1430	32	280	22
UYUR39	128	6	58	29
UYUR40	191	463	19	31
UYUR41	565	46	71	10
WAS42	3880	158	453	107
WAS43	1258	85	85	40
WAS44	592	134	141	37
WAS45	443	77	120	33
WAS46	806	341	123	85
WAS47	169	45	81	11
WAS48	510	225	108	75
WAS49	387	375	324	78

[8] n.d.= non detectable. The detection limit was estimated at 3µg/m^3

APPENDIX B: Kitchens with increased pollution and associated remarks

Code	24h PM_4 (µg/m3)		1h Max CO (ppm)		2006 kitchen location	Stove installation date	Remarks
	2005	2006	2005	2006			
AMU15	136	401	73	130	Separate room		The firewood used was slightly wet
AMU16	38	64			Separate room		
AMU17	44	161			Separate room		
AMU18	183	390			Separate room		
AMU19	192	554	66	135	Separate room		
AMU20	240	307	28	148	Separate room		
TUNG21	94	122	31	38	Separate room		
TUNG22	70	83			Same room		
TUNG28	177	211			Separate room		
UYUR02	94	617	74	138	Separate room		The pot is smaller than the hole in the stove
UYUR03			111	142	Same room		
UYUR06			31	83	Same room		
UYUR08	537	688	68	101	Separate room		
UYUR10			261	325	Separate room		The son prepared breakfast and the mother cooked at night. The mother isn't yet comfortable with the improved stove.
UYUR13			40	94	Separate room		The lady cooked in a small pot that didn't cover the entire stove hole.
UYUR31			13	37	Same room		
UYUR40	191	463	19	31	Separate room		The stove gives off too much smoke and the mother wasn't there